4. RESULTS AND DISCUSSION

The following sections present the results of the detailed data analyses that were performed to reduce the radiological data to a usable format and subsequent analyses that determined calibration parameters for the GPRS system.

4.1 GPRS Background Determination

The GPRS background count rate was determined in order to obtain the response of the detector to the naturally occurring radioactive material in the soils near the ARA-23 site. Two background data files were combined to make a large pool of data consisting of 782 data points. A statistical analysis was performed on the data, resulting in an average background count rate of 1032.8 ± 63.8 counts per second (cps). The statistical summary for the background data set is presented in Table 2, and a graphical presentation is shown in Figure 3.

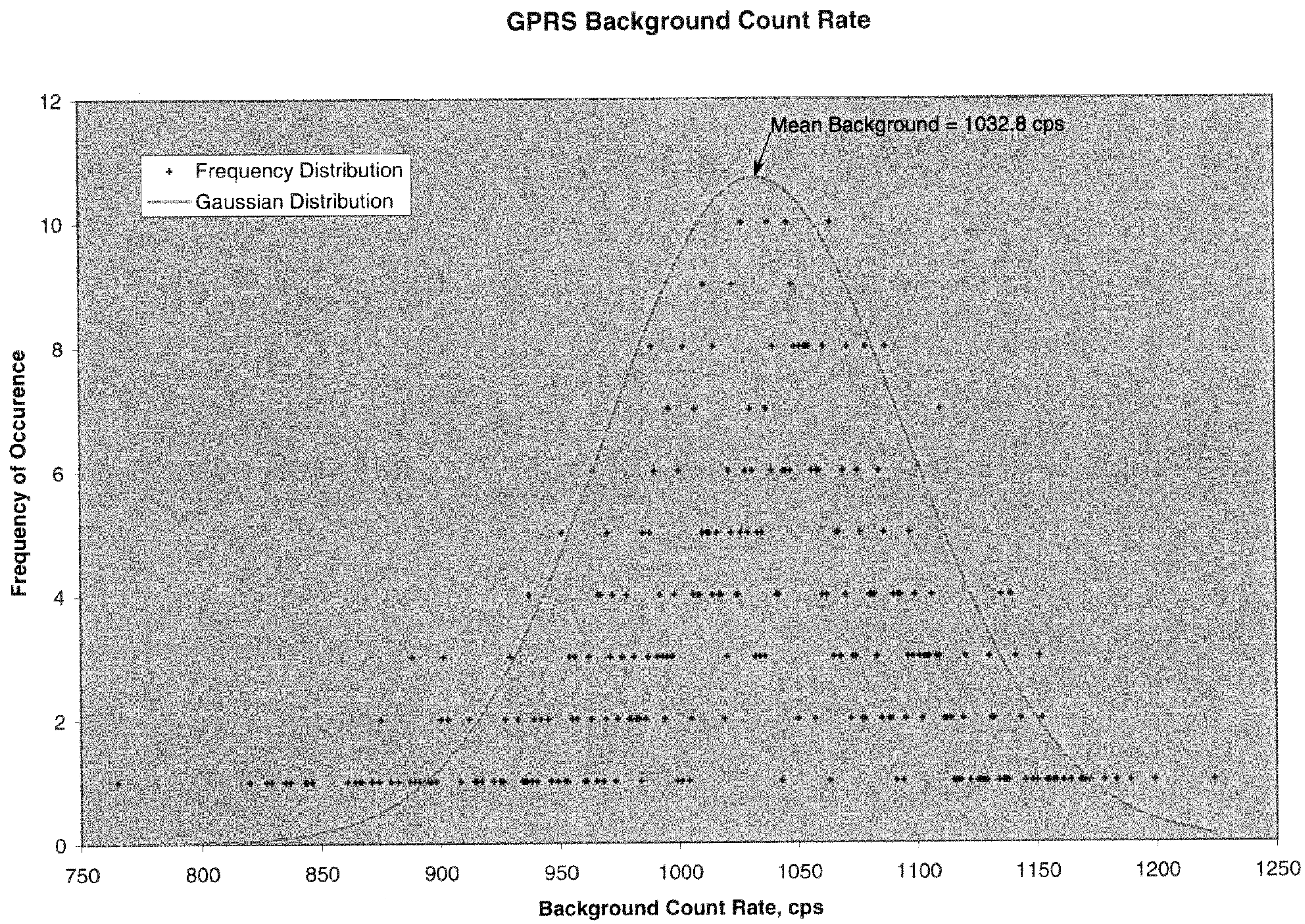

Figure 3. GPRS background count rate distribution.

Table 2. Statistical summary of background data set.

Number of Data Points	782
Minimum	765 cps
Maximum	1224 cps
Mean	1032.8 cps
Standard Deviation	63.8 cps
Standard Error	2.3

Figure 3 shows the frequency distribution of the 782 background data points. Additionally, a Gaussian distribution was fit to the data showing that the data are distributed normally about the mean value.

4.2 GPRS Cs-137 Calibration Curve

Measurements of the 30 calibration points along Transects A and B with the GPRS and the ISO-CART were completed in support of the GPRS calibration. The previously described measurement methods, and the data analysis and results that follow, were performed following the methodology presented by Josten (1997).

The GPRS data points on these plots correspond to the single point along the transect closest to the calibration measurement point. This is the easiest and most practical way to handle the data produced by the GPRS. It should be noted that a comparison was made between the single point GPRS value and an average of the five closest GPRS values to the surveyed calibration point, and there was little observable and no statistical difference between the two sets of values. This is demonstrated in Figures 4 and 5 for Transects A and B.

The first step in establishing a relationship between the GPRS net count rate data and the ISO-CART Cs-137 reported concentrations was to plot the GPRS and ISO-CART data as a function of position. Figures 6 and 7 show the profile of Transects A and B in terms of GPRS single point net count rate and Cs-137 concentrations with respect to the measurement point Northing coordinate value. As can be seen from these two figures, the relative response of both the GPRS and ISO-CART demonstrate that the two systems respond to the activity distribution across the transect in an almost identical fashion. There is, however, slightly more deviation observed in Transect A than there is in Transect B. Additionally, as can be seen from Figures 6 and 7, the Cs-137 concentration ranges, as reported by the ISO-CART, range from approximately 5 to 60 pCi/g, which encompass the 23 pCi/g remedial action goal.

The next step in establishing calibration factors was to plot the reported Cs-137 concentrations with respect to the GPRS net count rate. Table 3 lists the data values for each calibration point along the transects. Figure 8 is a graphical representation of the data.

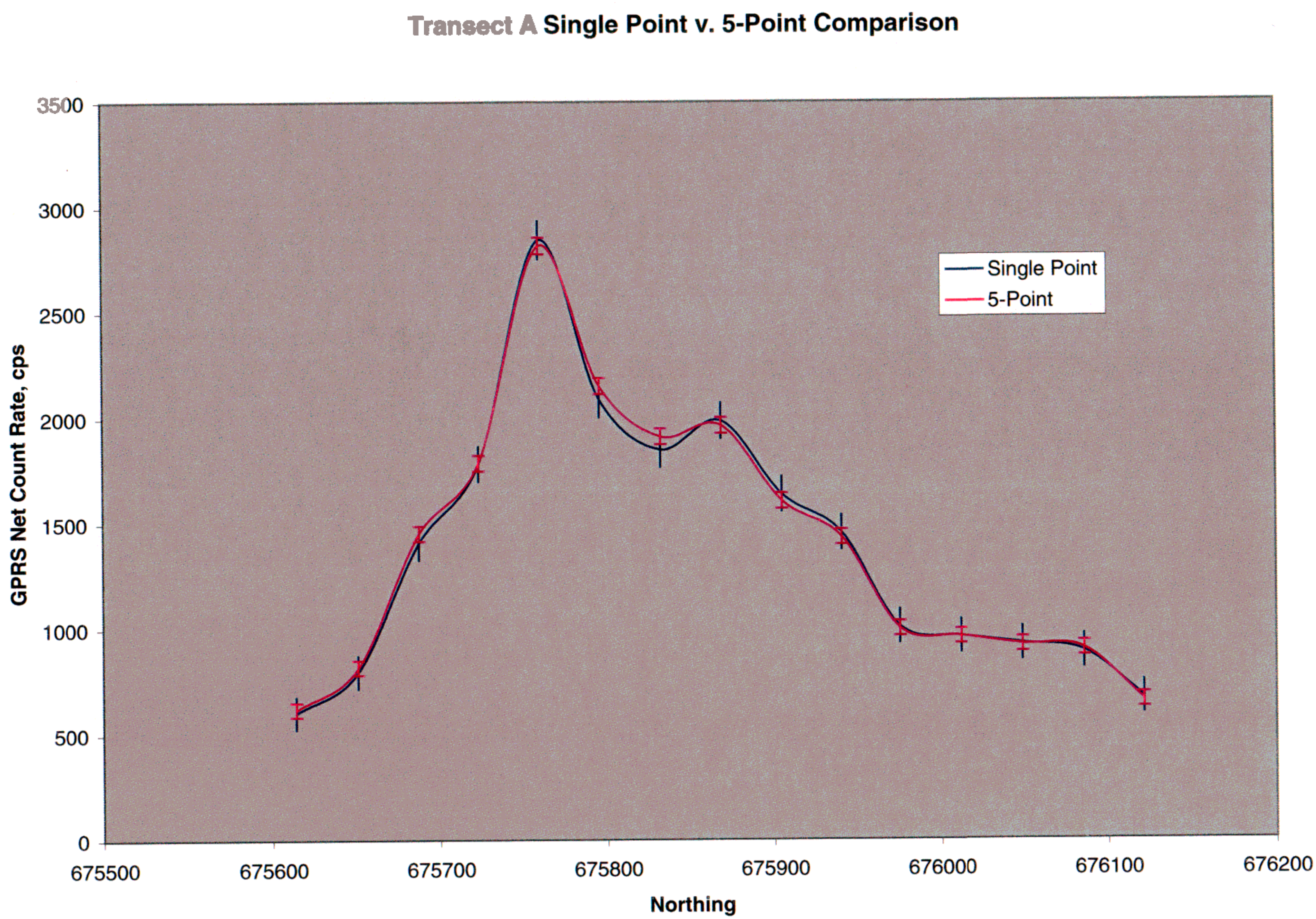

Figure 4. Transect A single-point versus five-point average count rate comparison.

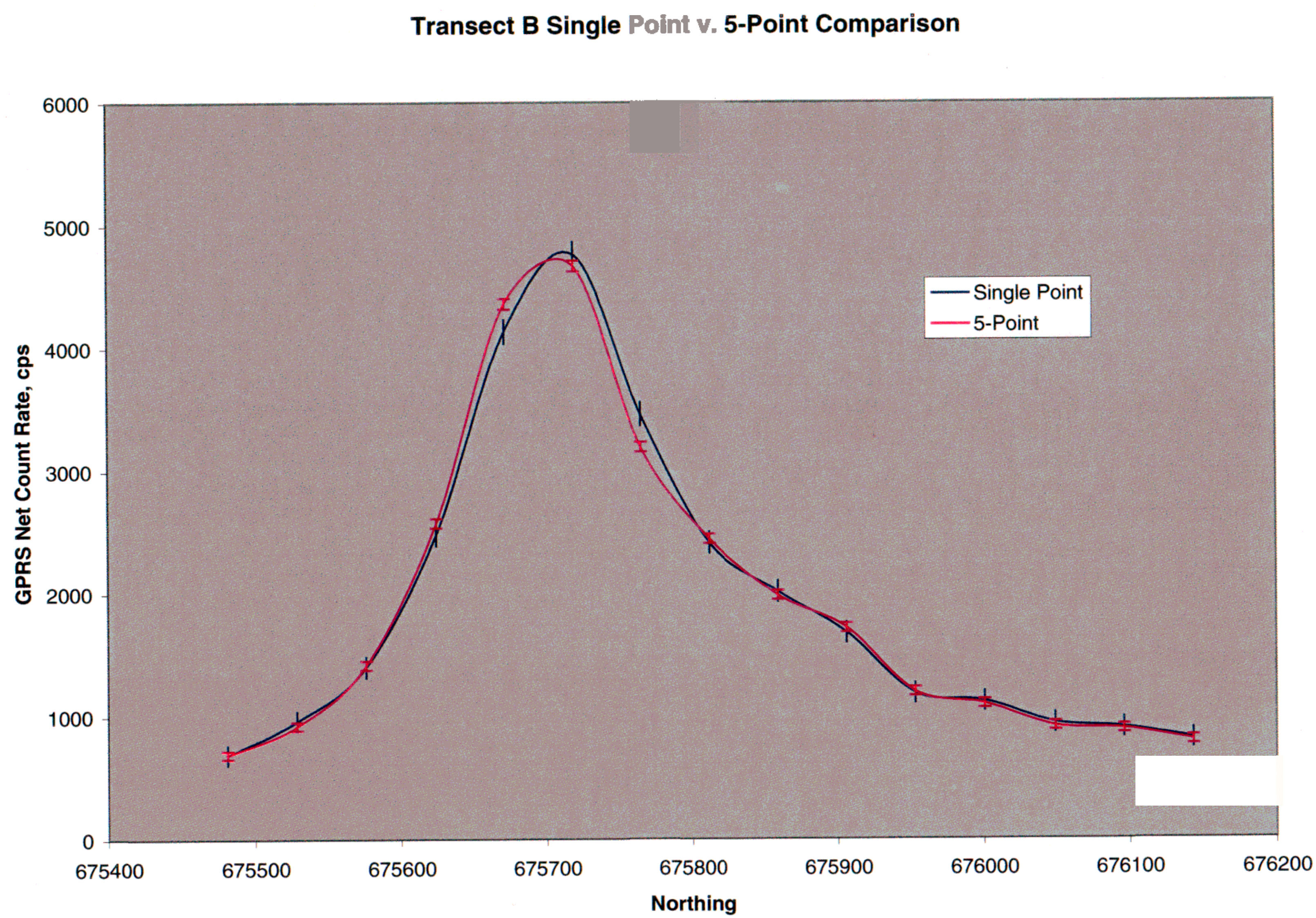

Figure 5. Transect B single-point versus five-point average count rate comparison.

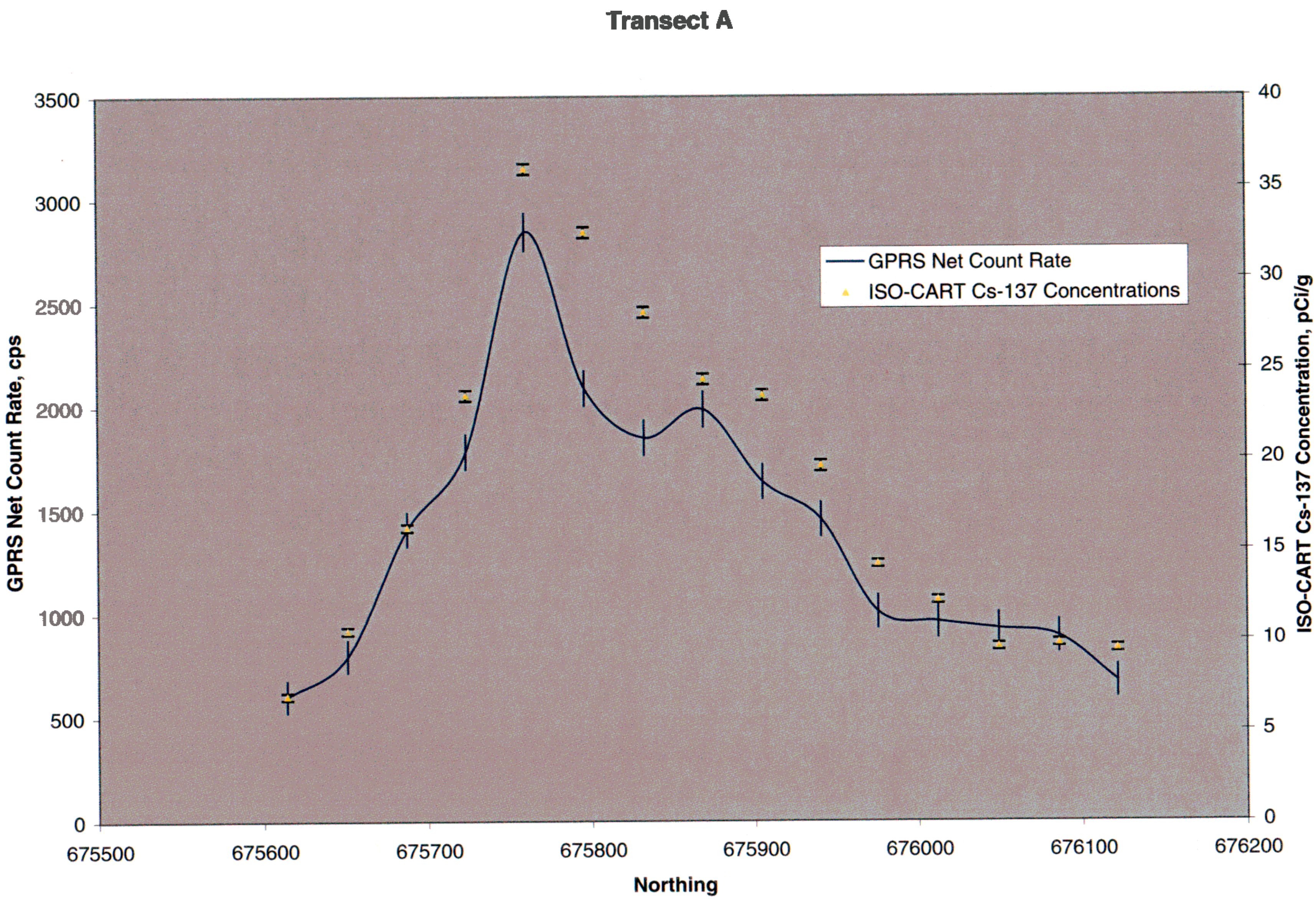

Figure 6. Transect A detail with GPRS count rate and ISO-CART results.

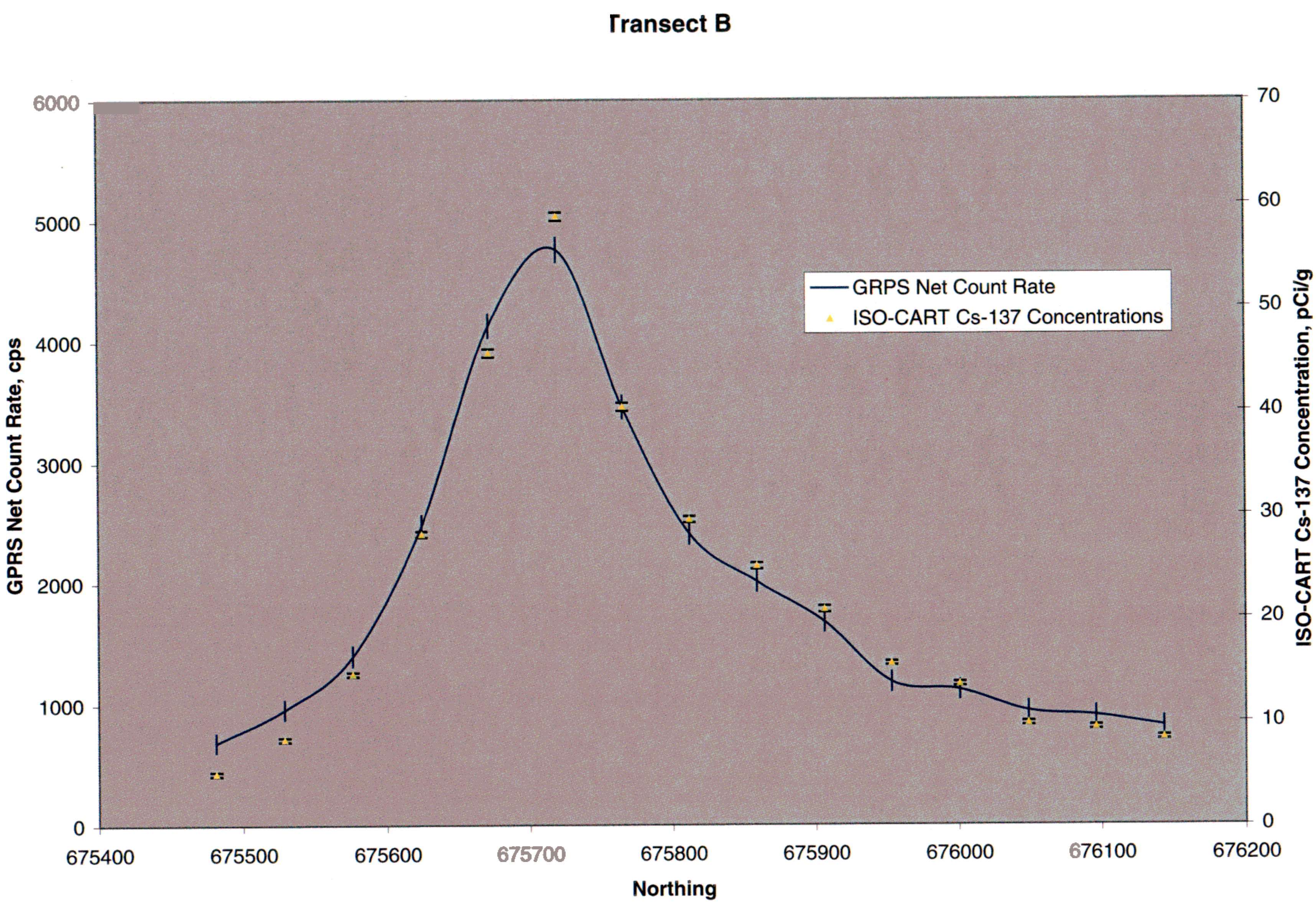

Figure 7. Transect B detail with GPRS count rate and ISO-CART results.

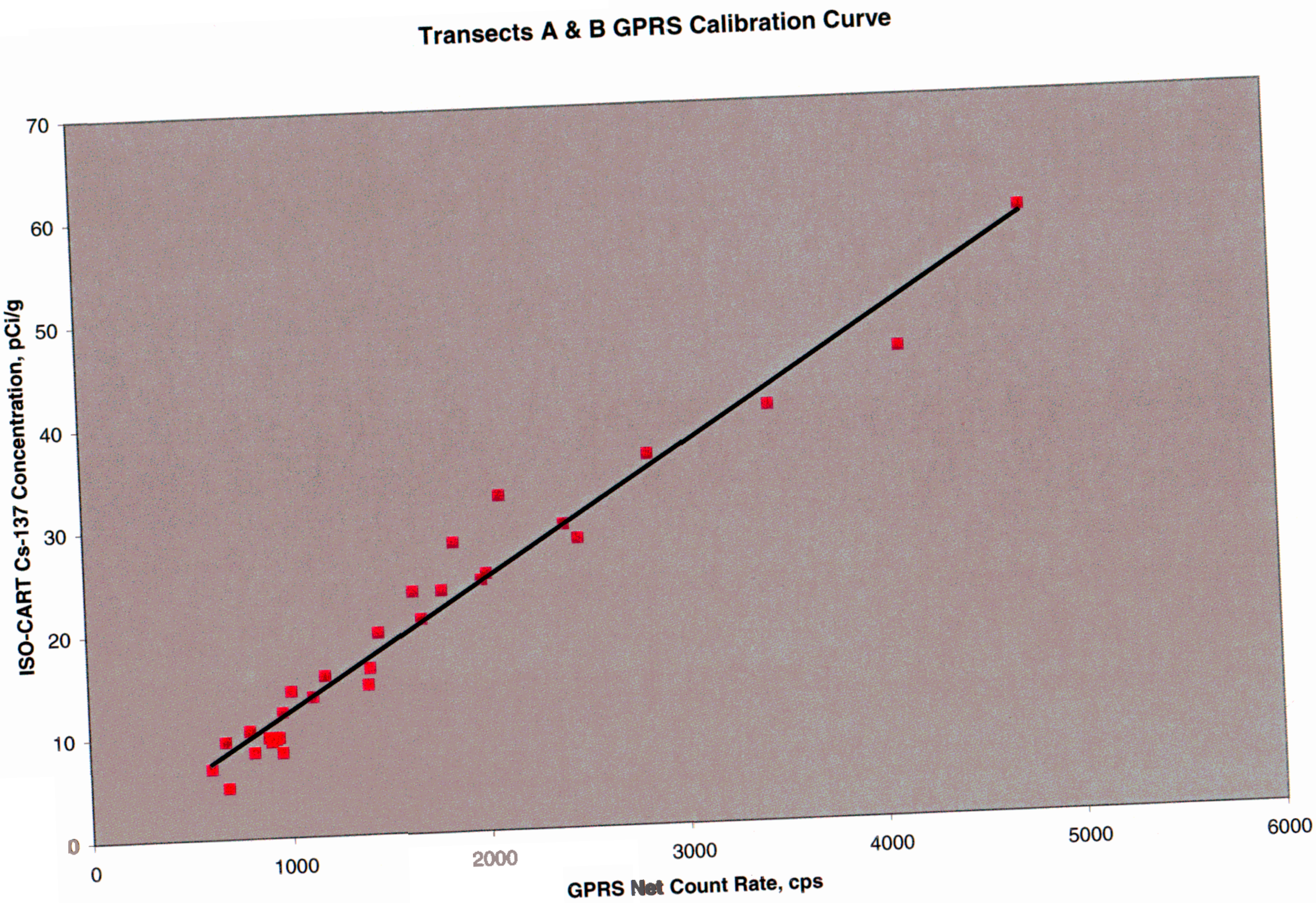

Figure 8. GPRS calibration curve, Transect A and Transect B data combined.

Table 3. Calibration point data values[a].

Calibration Point Designation	GPRS Net Count Rate, cps	ISO-CART Cs-137 Concentration, pCi/g	GPRS Calculated Cs-137 Concentration, pCi/g
A1	602.2 ± 75.5	6.9 ± 0.1	7.4 ± 1.0
A2	797.2 ± 76.8	10.5 ± 0.1	9.8 ± 1.0
A3	1409.2 ± 80.7	16.2 ± 0.1	17.2 ± 1.0
A4	1783.2 ± 83.0	23.5 ± 0.15	21.8 ± 1.1
A5	2845.2 ± 89.2	36 ± 0.15	34.8 ± 1.1
A6	2090.2 ± 84.8	32.5 ± 0.15	25.5 ± 1.1
A7	1851.2 ± 83.4	28.1 ± 0.15	22.6 ± 1.1
A8	1987.2 ± 84.2	24.4 ± 0.15	24.3 ± 1.1
A9	1638.2 ± 82.1	23.5 ± 0.15	20.0 ± 1.0
A10	1456.2 ± 81.0	19.6 ± 0.15	17.8 ± 1.0
A11	1010.2 ± 78.2	14.2 ± 0.1	12.4 ± 1.0
A12	963.2 ± 77.9	12.2 ± 0.1	11.8 ± 1.0
A13	928.2 ± 77.7	9.6 ± 0.1	11.4 ± 1.0
A14	892.2 ± 77.4	9.8 ± 0.1	10.9 ± 1.0
A15	674.2 ± 76.0	9.5 ± 0.1	8.3 ± 1.0
B1	817.2 ± 76.9	8.4 ± 0.1	10.0 ± 1.0
B2	904.2 ± 77.5	9.4 ± 0.1	11.1 ± 1.0
B3	943.2 ± 77.8	9.8 ± 0.1	11.6 ± 1.0
B4	1118.2 ± 78.9	13.6 ± 0.1	13.7 ± 1.0
B5	1182.2 ± 79.3	15.6 ± 0.1	14.5 ± 1.0
B6	1677.2 ± 82.3	20.8 ± 0.15	20.5 ± 1.1
B7	2013.2 ± 84.4	25 ± 0.15	24.6 ± 1.1
B8	2410.2 ± 86.7	29.5 ± 0.15	29.4 ± 1.1
B9	3460.2 ± 92.5	40.4 ± 0.2	42.3 ± 1.2
B10	4762.2 ± 99.3	58.8 ± 0.2	58.1 ± 1.3
B11	4132.2 ± 96.1	45.6 ± 0.2	50.5 ± 1.2
B12	2479.2 ± 87.1	28.1 ± 0.15	30.3 ± 1.1
B13	1398.2 ± 80.6	14.6 ± 0.1	17.1 ± 1.0
B14	958.2 ± 77.9	8.3 ± 0.1	11.7 ± 1.0
B15	684.2 ± 76.1	5 ± 0.1	8.4 ± 1.0

a. Measurement uncertainties reported at 1σ.

As can be seen from Figure 8, the relationship between the GPRS net count rate and the ISO-CART reported Cs-137 concentration is linear. This observation was also made by Josten, demonstrating that the GPRS is still functioning in a linear manner over the observed Cs-137 concentration range. Linear regression analysis performed on the data resulted in an equation that may be used to convert net count rate data from the GPRS to Cs-137 concentrations at the ARA-23 site. The general form of the equation is as follows:

$$C = K_1 \cdot A + K_2.$$

Where:

C	=	Cs-137 concentration
A	=	Observed net GPRS count rate
K_1, K_2	=	Best fit parameters as determined by linear regression analysis.

Values for K_1 and K_2, as determined by linear regression, are as follows:

K_1	=	0.0122 (pCi/g)/cps
K_2	=	0.0455 pCi/g.

This results in the following equation:

$$C = 0.0122\ [(pCi/g)/cps] \cdot A\ (cps) + 0.0455\ (pCi/g).$$

Similarly, the uncertainty in the Cs-137 concentration, as reported by the GPRS data is:

$$\sigma_C = 0.0122\ [(pCi/g)/cps] \cdot \sigma_A\ (cps) + 0.0455\ (pCi/g).$$

Where:

σ_C	=	Cs-137 uncertainty
σ_A	=	Net count rate uncertainty.

The net count rate uncertainty, σ_A, may be calculated as follows (Knoll 1989):

$$\sigma_A = \sqrt{\sigma_G^2 + \sigma_{Bkg}^2}.$$

Where:

σ_G	=	Gross count rate uncertainty
σ_{Bkg}	=	Background count rate uncertainty.

The background count rate uncertainty, σ_{Bkg}, is given by the standard deviation as reported in Table 2. This value is 63.8 cps. The gross count rate uncertainty, σ_G, based on nuclear counting statistics, is simply the square root of the gross counts divided by the count time (Knoll 1989), which, for the GPRS measurements, are all 1-second.

4.3 GPRS Calibration Accuracy

The accuracy of the GPRS calibration was evaluated using the following two methods: 1) comparison of the GPRS calculated Cs-137 concentrations at the calibration points along Transects A and B with the ISO-CART data, and 2) an independent comparison between GPRS calculated concentrations and ISO-CART reported concentrations at points D1, D2, and D3.

Figure 9 compares the GPRS calculated concentrations with the ISO-CART reported concentrations for the calibration points along Transects A and B. As expected, the correlation is linear, and shows a nearly 1 to 1 relationship between the two data sets (listed in Table 3) as indicated by the slope of the line (0.99).

Three additional measurement points (D1, D2, and D3) were identified at the ARA-23 site to verify the accuracy of the new GPRS calibration equation in determining the Cs-137 concentration in soils. Table 4 lists and compares the results of the GPRS measurements with the ISO-CART measurements for measurement points D1, D2, and D3. The GPRS values are consistently high for these measurement points, averaging 22.9%. The two potential contributors to this bias are: 1) the ISO-CART measurements were made with approximately 1 in. of snow on the ground, and 2) the Cs-137 contamination along the haul road (where D1, D2, and D3 are located) is distributed deeper than the assumed 1-in. windblown contamination distribution associated with Transects A and B.

It is most likely that the snow layer on the ground is the primary contributor to the bias. This is due to the attenuation of the Cs-137 gamma-rays by the snow. As a result, the computed Cs-137 concentrations reported by the ISO-CART are biased low. It should be noted that the original ISO-CART data for points D1, D2 and D3 were increased by 25% to account for the snow layer. This was based on observed bias in ISO-CART measurements of points B13 and B14 before and after the snowfall. The actual snow depths at points B13, B14, D1, D2 and D3, within the ISO-CART field of view, were not measured. Additionally, the deeper distribution of Cs-137 along the SL-1 haul road would bias the GPRS data high due to the increased signal as seen by the detector. As a result, it is possible that a 25% increase at locations D1, D2 and D3 was less than the true correction.

4.4 GPRS Scan MDC

A question that is often posed with regards to radiation measurement systems is *"What is the smallest amount of activity that can be seen with this system?"* The GPRS is the system in question in this instance, and the *a priori* detection limit is the system parameter that is desired. Typical protocol for laboratory instrumentation is to have a lower limit of detection that is at least a factor of ten less than the action level, or remedial action goal. The U. S. Nuclear Regulatory Commission (NRC) has published guidance for determining lower limits of detection, or minimum detectable concentrations (MDCs) for survey instrumentation (NRC 1997). The following is a calculation of the GPRS scan MDC as determined from NUREG 1507.

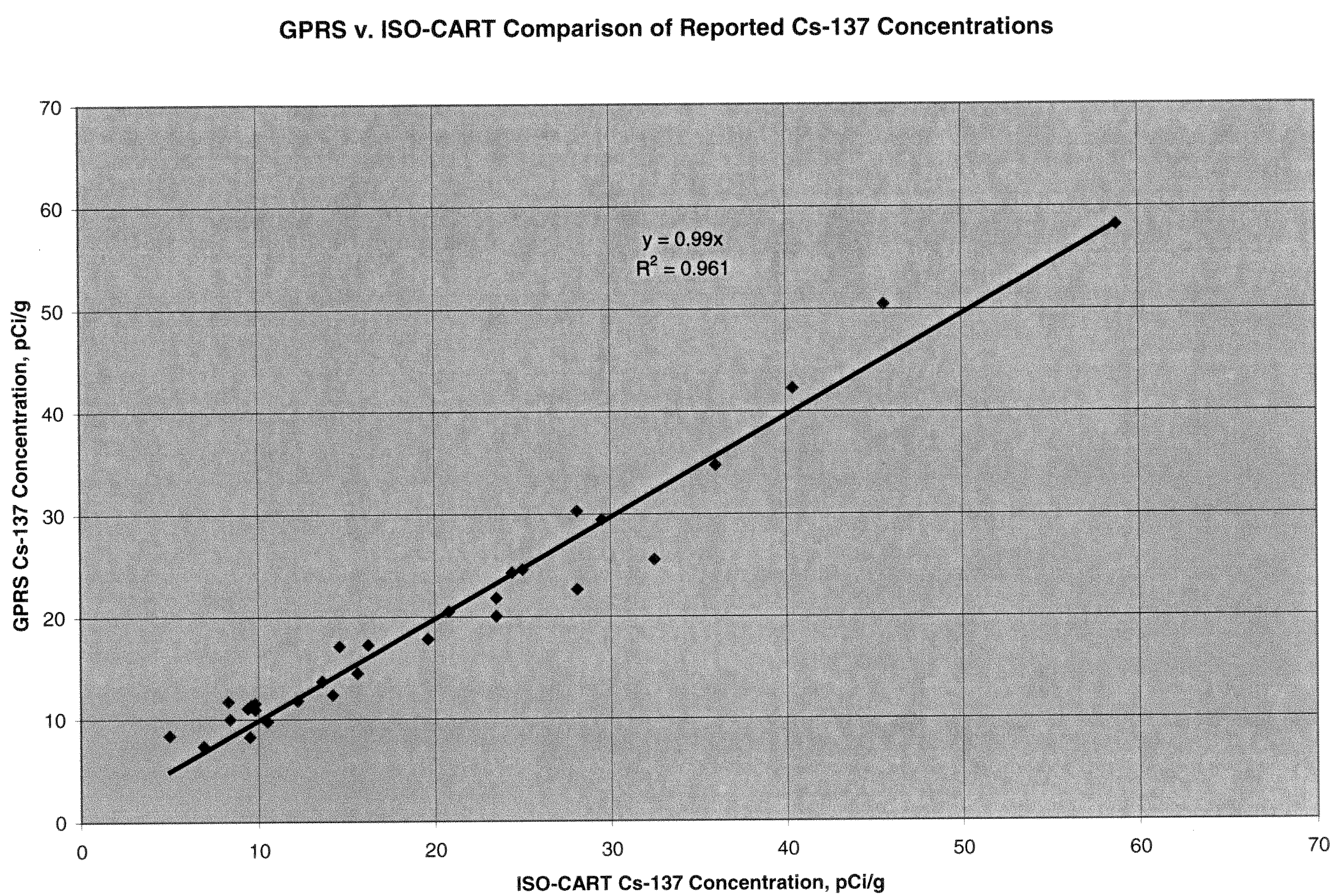

Figure 9. Comparison of GPRS and ISO-CART Cs-137 concentrations.

Table 4. GPRS calibration accuracy[a].

Point Designation	Reported Cs-137 Concentration, pCi/g		Difference
	GPRS	ISO-CART	
D1	31.7 ± 0.5	28.7 ± 0.4	+9.5%
D2	27.7 ± 0.5	18.5 ± 0.3	+33.2%
D3	23.8 ± 0.5	17.6 ± 0.4	+26.1%

a. Measurement uncertainties reported at 1σ.

The minimum detectable number of net source counts, s_i, during a given count interval, i, is given by (NRC 1997):

$$s_i = d'\sqrt{b_i}.$$

Where:

s_i Minimum detectable number of net source counts during a count interval, i

d' Index of sensitivity

i Count interval

b_i Background count rate during count interval i

The specified count interval, i, for the GPRS is 1 second, and the background count rate is taken as 1,032.8 cps. The index of sensitivity, d', is a value that reflects the acceptable Type I and Type II error rates. Values for the index of sensitivity, d', have been calculated by transforming Type I and Type II error rates to z values, and taking the difference. These values are tabulated in Table 6.1 of NUREG 1507 (NRC 1997). Using Type I and Type II error values of 0.05 and 0.20, a value of 2.48 is obtained for the index of sensitivity. Therefore, the minimum detectable number of net source counts for the GPRS is then;

$$s = 2.48 \cdot \sqrt{1032.8}$$

$$s = 79.7\ counts.$$

Using the 1 second time interval of the GPRS, the minimum detectable count rate, *MDCR*, is then:

$$MDCR = 79.7\ cps.$$

The desired value, however, is the minimum detectable concentration for Cs-137. This can be calculated using the conversion equation derived in Section 4.2, substituting the MDC for the concentration, C:

$$MDC = 0.0122\,[(pCi/g)/cps] \cdot 79.7\,(cps) + 0.0455\,(pCi/g)$$

$$MDC = 1.0\ pCi/g.$$

The calculated scan MDC for the GPRS is found to be well below the 23 pCi/g remedial action goal for the Cs-137 contaminated soils at ARA-23.

5. SUMMARY AND RECOMMENDATIONS

Radiation measurements were made at the ARA-23 CERCLA site using the INEEL GPRS and ISO-CART systems. A calibration function was developed for calculating and converting GPRS net count rate data to Cs-137 concentrations at the ARA-23 site. Additionally, it was shown that the accuracy of the GPRS measurements, with respect to the ISO-CART, was within 25%, which for the purposes of field screening, is adequate. Additionally, the utility of the GPRS in identifying Cs-137 hot spots at or above the 23 pCi/g remedial action goal was verified with the calculation of the minimum detectable concentration. As shown in Section 4.4, the scan MDC for the GPRS is 1.0 pCi/g.

Although the study presented here demonstrates that the GPRS can be used to quantify Cs-137, the following precautions must be observed:

- The calibration developed here is specific to the ARA-23 CERCLA site, and specific to Cs-137. This calibration **should not** be applied to GPRS data at any other contaminated site. If it is determined that quantitative measurements using the GPRS at other contaminated sites would be cost effective, then a study similar to the one presented here, including determination of a site specific background, could be conducted. Additionally, it must be verified through analytical samples and/or ISO-CART measurements that the contamination is associated with a single gamma emitter (i.e. Cs-137). If multiple gamma emitters are present, it may still be possible to use the GPRS; however, a consistent ratio must be present between the gamma emitters.

- The GPRS background count rate for the ARA-23 site should be re-evaluated just prior to the OU 5-12 Phase II soil removal action, currently scheduled for FY 2004. Changes or modifications to the GPRS may affect the system response to radiation. Additionally, changes to the soil, such as removal of the top layer, may result in lower background count rates; due primarily to the removal of the Cs-137 that is present due to atmospheric weapons testing. The average background Cs-137 concentration, due to atmospheric weapons testing and INEEL operations, is 0.44 pCi/g (Rood et al. 1996). It is recommended that prior to the OU 5-12 Phase II soil removal a background study be conducted. This study can be conducted by excavating the top 3 in. of soil from a previously undisturbed area and by measuring the background count rate at a minimum of 30 locations through use of the GPRS. The GPRS collects a data point every second, therefore a fairly small area would require excavation (i.e., 60×300 ft, 1800 ft^2). Based on the calculations presented in this EDF, the probability of making a Type II error is 20%; however, if the background count rate of excavated soils is statistically different from the background count rate of undisturbed soils, then the probability of committing a Type II error will also increase. The risk associated with this would be high considering that hot spots above the remedial action goals could be missed resulting in the site being incorrectly declared "clean." Accurate field measurements are required to ensure that only contaminated soil is removed, thereby minimizing the disposal volume, and ensuring that declaring the site clean after the remedial action is correct.

- The calibration equation presented in this report assumes a 1-in. uniform distribution of the Cs-137. An evaluation of the depth distribution presented in Josten (1997) demonstrates that this is an accurate depiction of the actual distribution of Cs-137 at ARA-23. In instances where the contamination is actually distributed deeper than 1 in. (such as the SL-1 haul road), the GPRS response may overestimate the concentrations for the first few inches of soil. However, as soil is removed, the actual distribution will approach the assumed 1-in. distribution resulting in more accurate GPRS measurements.

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